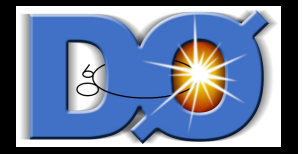


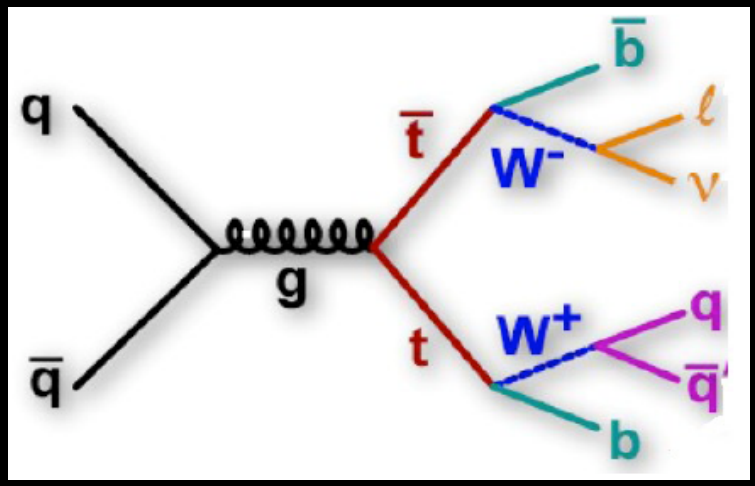
Searches for New Physics in the Top Quark Sector at the Tevatron

Ford Garberson
(Yale University)

CDF Top Results: http://www-cdf.fnal.gov/physics/new/top/public_tprop.html
D0 Top Results: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

Introduction

- Thousands of "top quarks" have been produced at the Tevatron
  - How do we test if they are Standard Model?



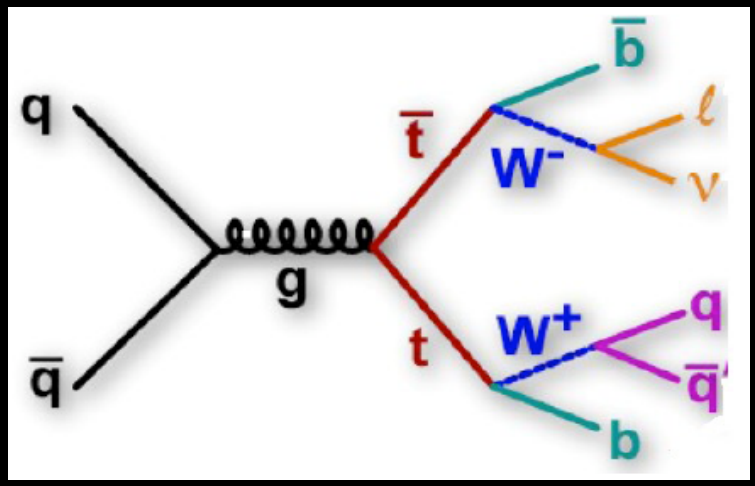
Typical $t\bar{t}$ Production process at Tevatron

- The direct approach:
  - Search data for presence of specific non-SM processes
    - Comparison with simulation of new processes
- The indirect approach
  - Measure properties and compare with SM expectations
  - Top mass, charge, spin, cross section, kinematics

Introduction

- Thousands of "top quarks" have been produced at the Tevatron
  - How do we test if they are Standard Model?

Covered in this talk and the next one



Typical $t\bar{t}$ Production process at Tevatron

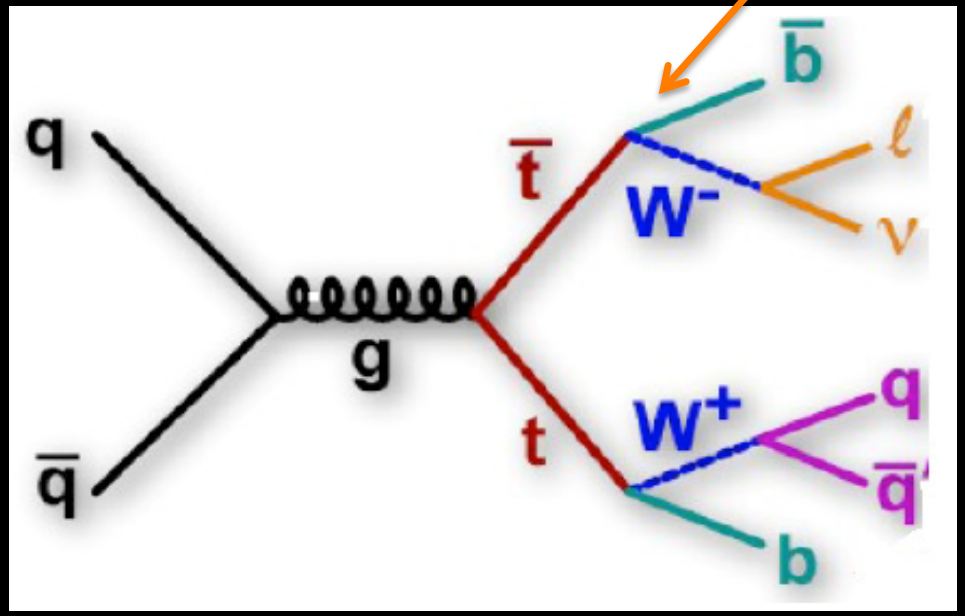
- The direct approach:
  - Search data for presence of specific non-SM processes
    - Comparison with simulation of new processes
- The indirect approach
  - M… …ties and
  - Top … …ge, spin, cross section, kinematics

Dedicated Talks in other Sessions

Identification of Top Quarks

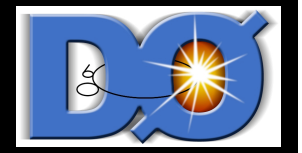
- What we expect if the Standard Model is correct …

Tops Almost Always Decay to Wb ~100% of the time



- Final states depend on W decay modes. Expect …
  - 2 *b*-jets
    - Can tag them based on lifetime, etc
  - 0, 2, or 4 other jets
  - Usually study modes with 1 or 2 leptons (less background)
    - Plus missing energy from neutrino(s)

Searches for Massive X=>$t\bar{t}$



- A number of scenarios predict massive particles decaying to $t\bar{t}$
  - Searches: reconstruct invariant $t\bar{t}$ mass, search for excesses beyond standard model

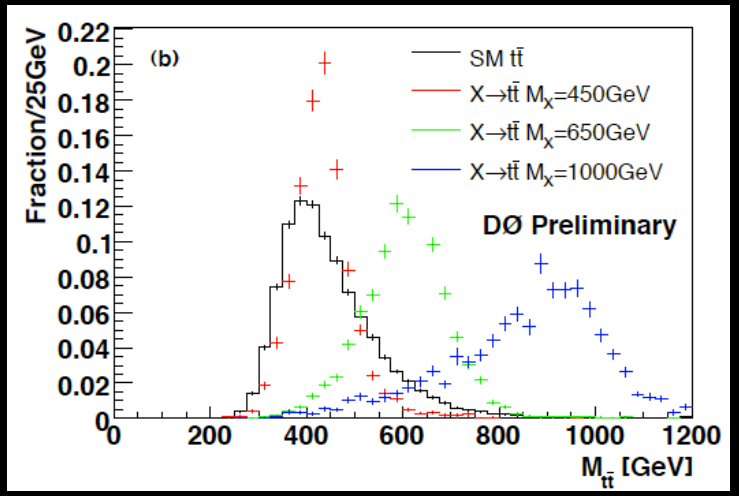
- D0 search: 3.6 fb^{-1} in single lepton channel
  - Require isolated lepton, missing energy, at least three jets, one or more *b*-tagged
    - Allows a jet to be lost due to merging: especially important for massive X decays

D0 X=>$t\bar{t}$ Resonance Results

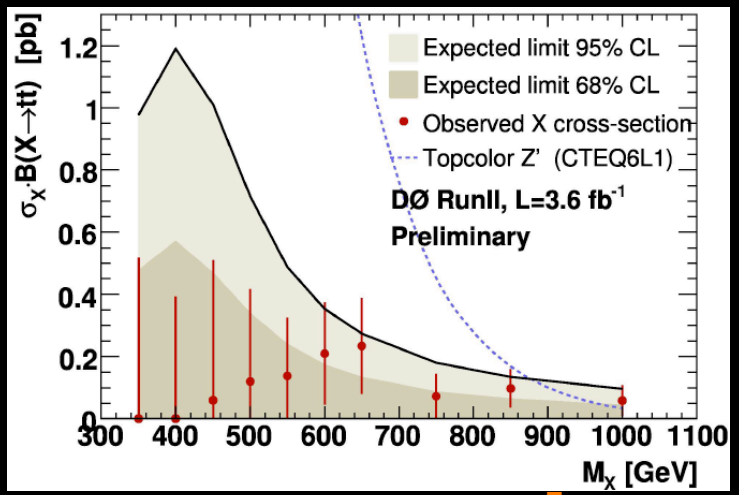
- Reconstruct $t\bar{t}$ invariant mass from four leading jets, MET
  - Use simulation of X=>$t\bar{t}$ processes, Poisson probability for signal consistency:

$$P(\sigma, m) = \prod_{i=1}^{n_{bins}} e^{-\mu_i(\sigma,m)} \frac{\mu_i(\sigma, m)^{n_i}}{n_i!}$$

- Largest excess less than 2 sigma at X mass ~650 GeV
  - Set 95% confidence limits for various spin, width hypotheses for X particle



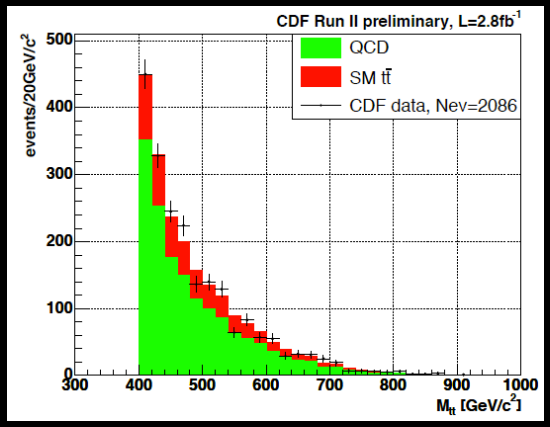
Invariant mass Predictions for SM $t\bar{t}$, X=>$t\bar{t}$ at different masses



D0 95% Limits on X=>$t\bar{t}$ Cross Section for 3.6 fb^{-1}

CDF X=>$t\bar{t}$ Resonance Results

- CDF has recently done this search in the all-jets top-decay channel
  - Reduce QCD background with Neural Network Selection
    - Tests/systematics from many control regions
- $M_{t\bar{t}}$ reconstruction from matrix element + transfer functions technique
  - Described in detail in top-mass talk



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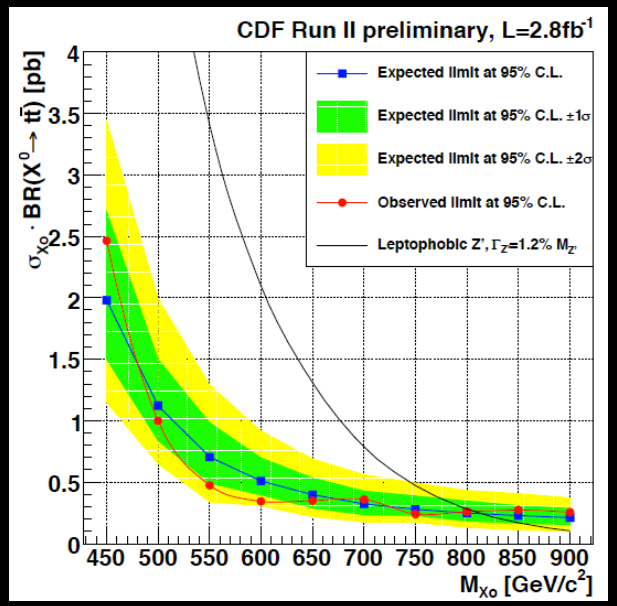
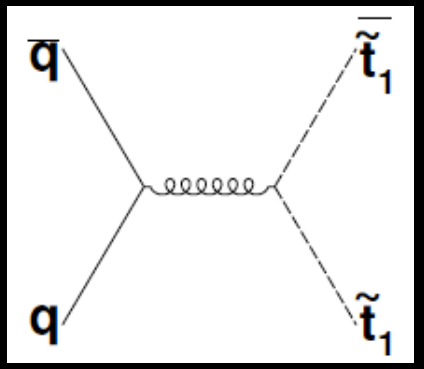


CDF 95% Confidence limits on X=>$t\bar{t}$ Cross section in All-Jet Channel (2.8 fb^{-1})

Search for Stop Production

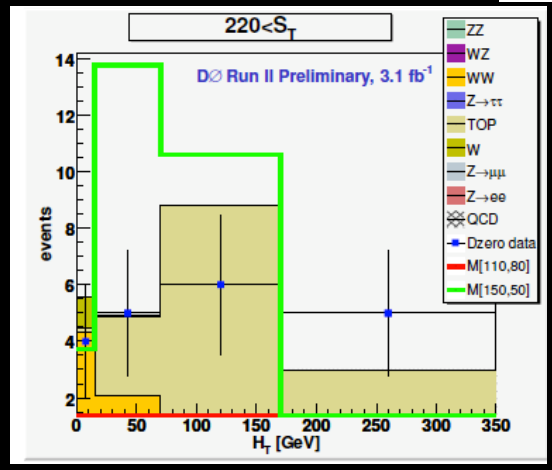
- Lightest stop quark may be too light to decay into top
  - Chargino may be light.
    - So CDF searches for $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^+$
  - If chargino is heavier then forbidden
    - So D0 searches for $\tilde{t}_1 \rightarrow b\tilde{\nu}^0\bar{l}^+$



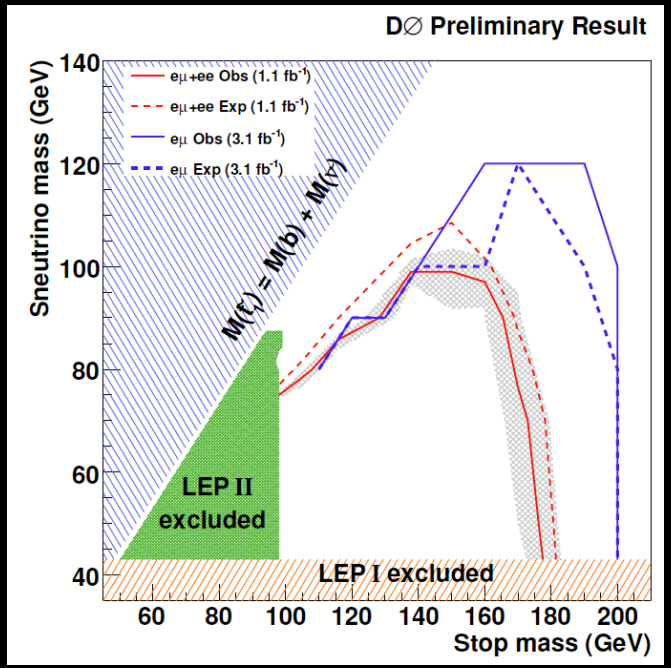
- D0 Search: require low Pt opposite sign muon-electron events
  - Very small Standard Model backgrounds
  - Reduce Z=>tau tau and fake QCD backgrounds:
    - Require MET > 18 GeV
    - Require that MET is not close to either lepton

D0: Search for Stop to Sneutrino Decays

- Search for excess in kinematic distributions
  - HT: scalar sum of jet pT
  - ST: HT + lepton pT + missing transverse energy
    - Example: for heavy stop expect high ST, low HT
- No excess found
  - Set limits using ROOT TLimit package
    - Assuming 100% branching ratio of stop to this decay channel



Expected Excesses at high ST



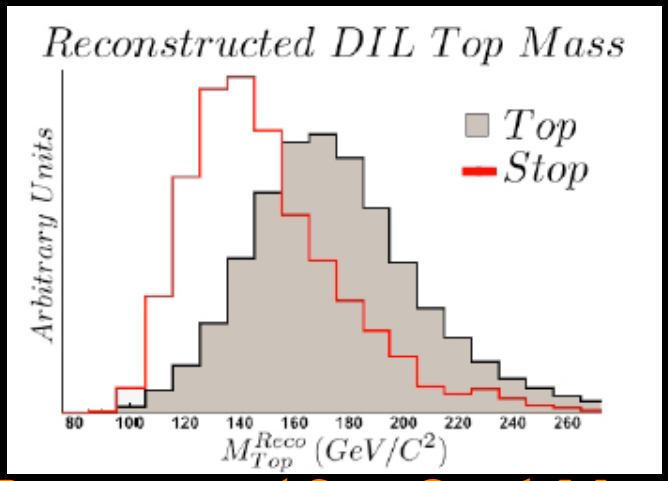
3.1 fb^{-1} 95% Confidence Limits on Masses

CDF: Search for Stop to Chargino Decays

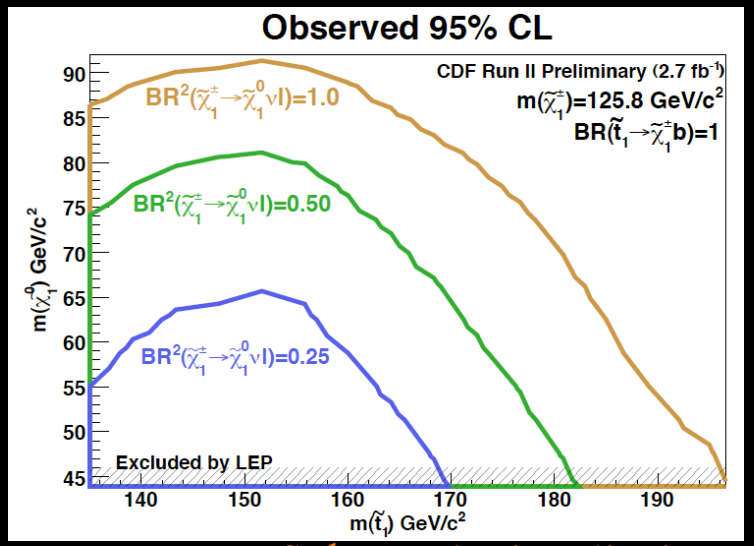
- CDF searches for stop under light chargino scenario:

$$\tilde{t}\bar{\tilde{t}} \rightarrow b\bar{b}l^{-}\bar{l}^{+}\nu\bar{\nu}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

- Reconstruct stop masses
  - Approximations and chi2 minimization to deal with under-constrained system
- No excess, set limits based on stop mass fit



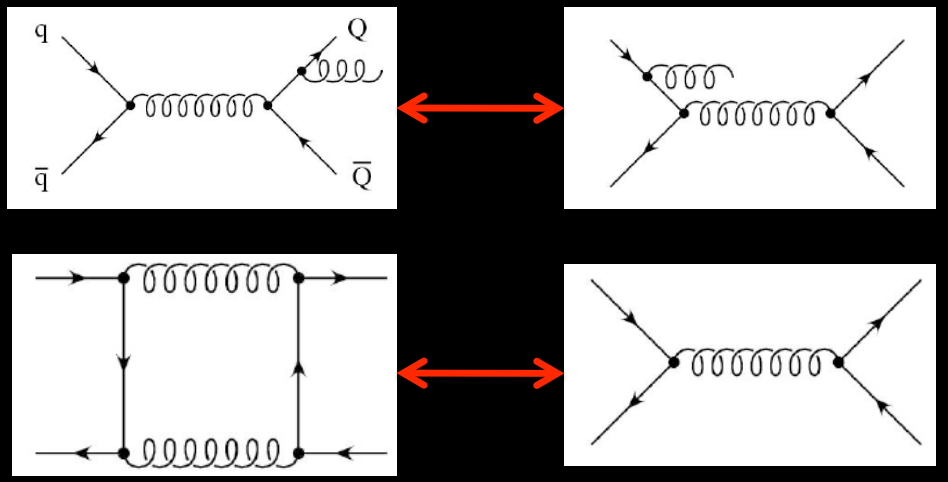
Reconstructed Stop Quark Mass



CDF 2.7 fb^{-1}: Exclusion limits depend on Chargino mass and Chargino to Neutralino BR

Top Charge Asymmetry

- At LO expect (almost) equivalent directions for t and $\bar{t}$ production
  - But at NLO, two effects cause $\bar{t}$ to be produced preferentially in anti-quark direction and vice versa



NLO Interferences that Cause Asymmetry

- An indirect search: is top quark asymmetry as expected?
  - Standard Model: expect A_{fb} = 0.05 +/- 0.015

$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

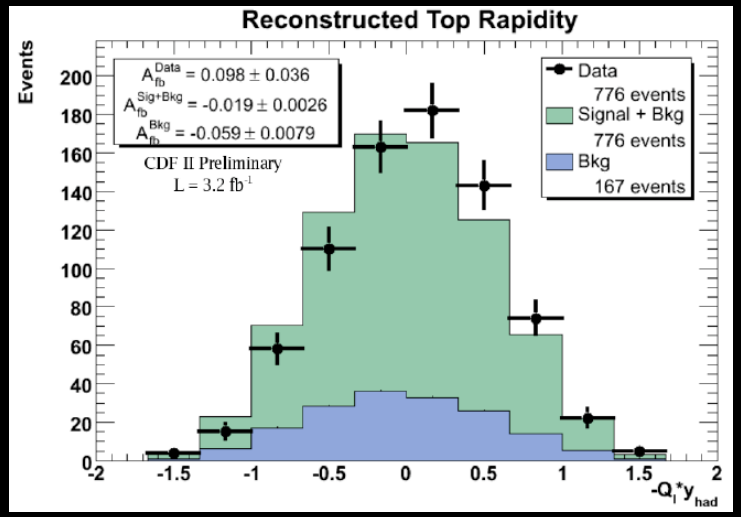
Results

- Raw asymmetry ~0.10
  - Subtract off backgrounds: 0.14
  - Event selection biases Afb, and reconstruction of direction smears it
    - Correct and unfold to determine $t\bar{t}$ Afb in $p\bar{p}$ rest-frame. At 3.2 fb^{-1}:

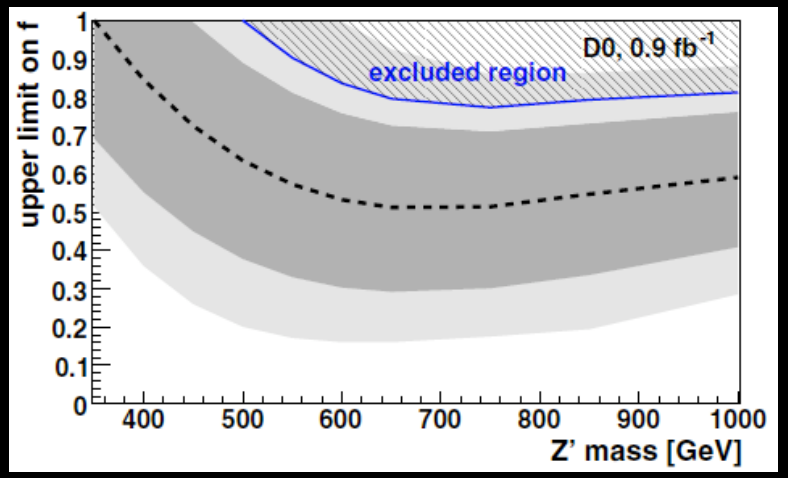
$$A_{fb} = 0.193 \pm 0.065(\text{stat}) \pm 0.024(\text{syst})$$

- Consistent with 0.9 fb^{-1} published D0 result:

$$A_{fb} = 0.12 \pm 0.08(stat) \pm 0.01(syst)$$



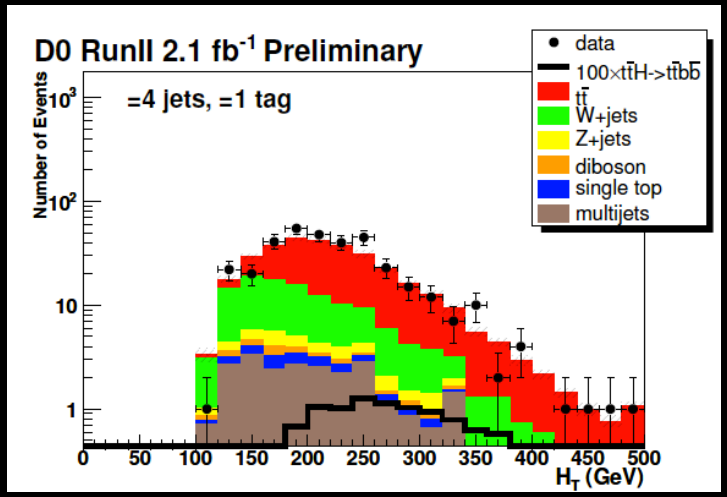
Noticeable Asymmetry in Reconstructed +Charge Top Quark Rapidity



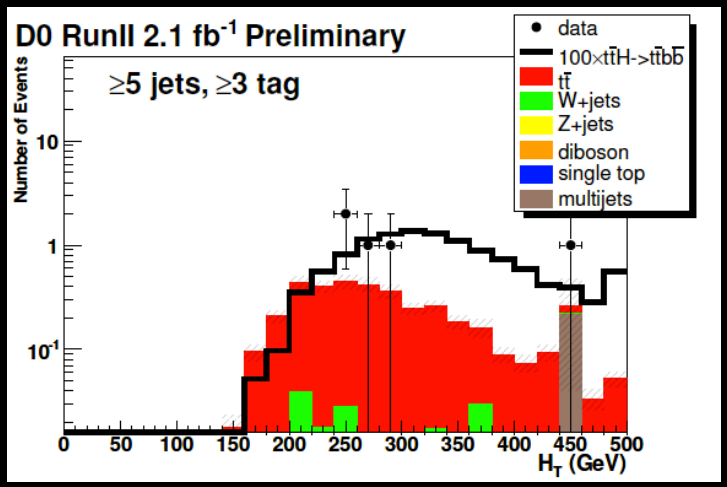
D0 Translates Afb Results into Exclusion limits on massive Z=>$t\bar{t}$ Rate

Search for $t\bar{t}H$ Production

- Cross section for Standard Model $t\bar{t}$+Higgs production too small to observe at Tevatron
  - But sensitive to new physics scenarios
- Search in single-lepton $t\bar{t}$ sample
- Three variables to discriminate signal:
  - Six bins in #jets, #tagged jets
  - Use distribution of Sum HT in each bin



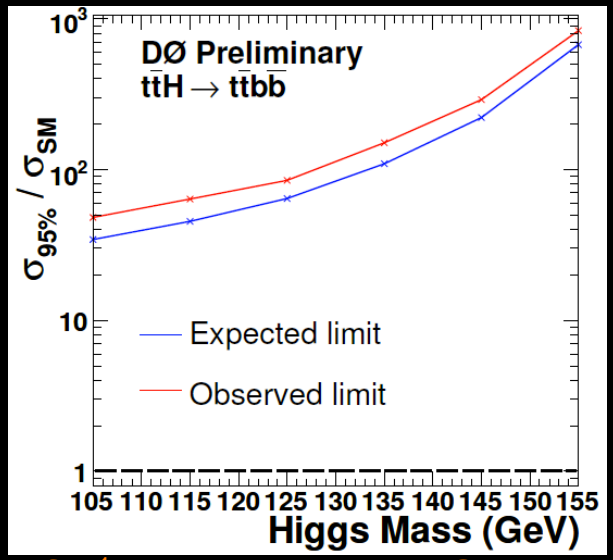
Data and Expectations for events with 4 jets, one *b*-tagged (background validation)



Data and Expectations for events with >= 5 jets, >=3 *b*-tagged (possible signal)

Extraction of Limits

- No signal excess found so set limits
  - Standard frequentist approach used by Higgs group
  - Also set limits on exotic physics scenario
    - Massive gluon coupling to heavy top quark



2.1 fb^{-1} Expected and Observed Limits on SM $t\bar{t}H$ production

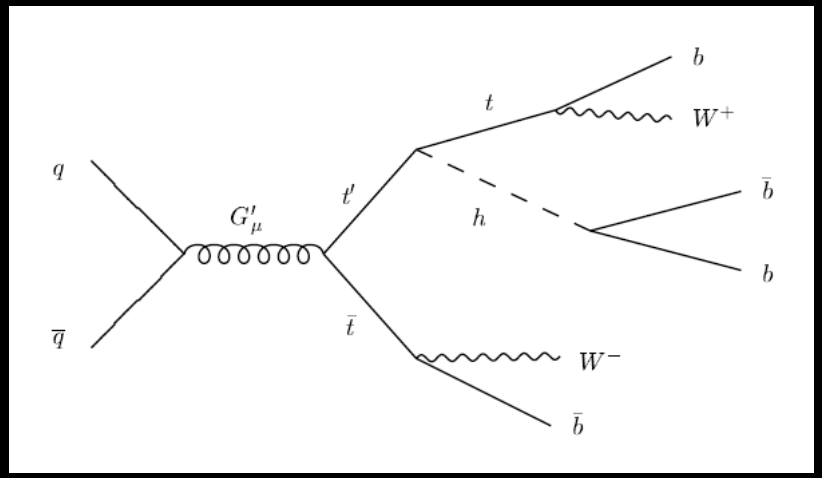
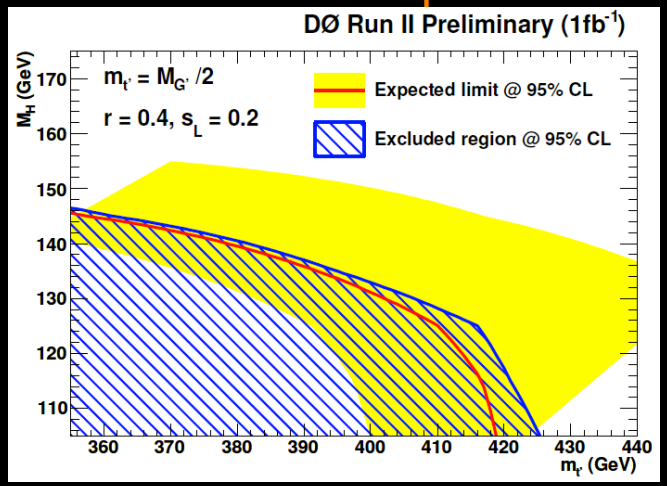


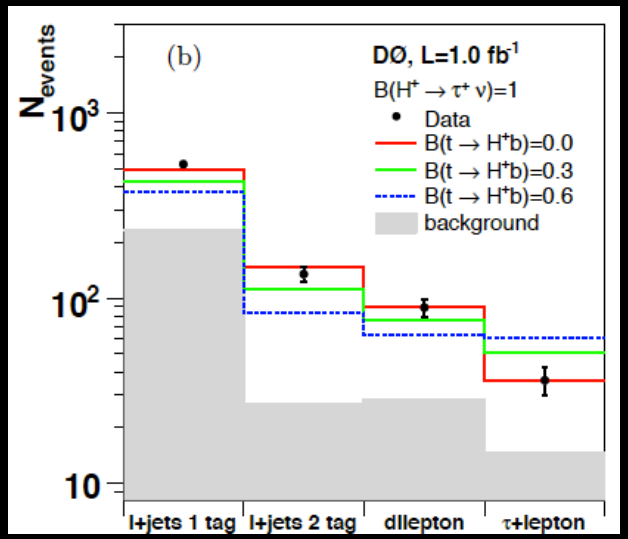
Diagram for Massive Gluon +heavy top Search



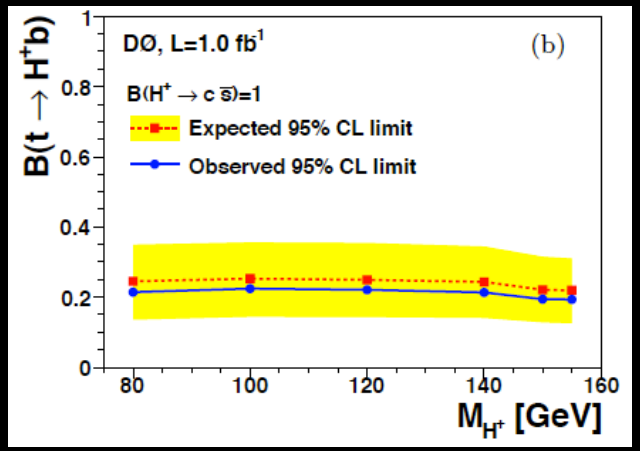
Phase-Space Excluded in Massive Gluon+Heavy top scenario

Search for t=>H⁺b

- Does top ever decay into charged Higgs?
  - D0, 1 fb^{-1}: Search in H$^+$ => tau nu, H$^+$ => cs decay channels
- Counting experiment
  - #events in channels based on number of jets, electrons, muons, taus, *b*-tags
  - No excess seen, set limits on t => H$^+$b BR as function of H$^+$ mass, fraction of H$^+$'s that decay tauonically or hadronically



#Observed Events in Four categories of decay channels. Red: Standard Model



BR Limits on t=>H⁺b, hadronic H⁺ decays. Yellow: 1-sigma SM Expectations.

Search for t=>H^+b in NMSSM

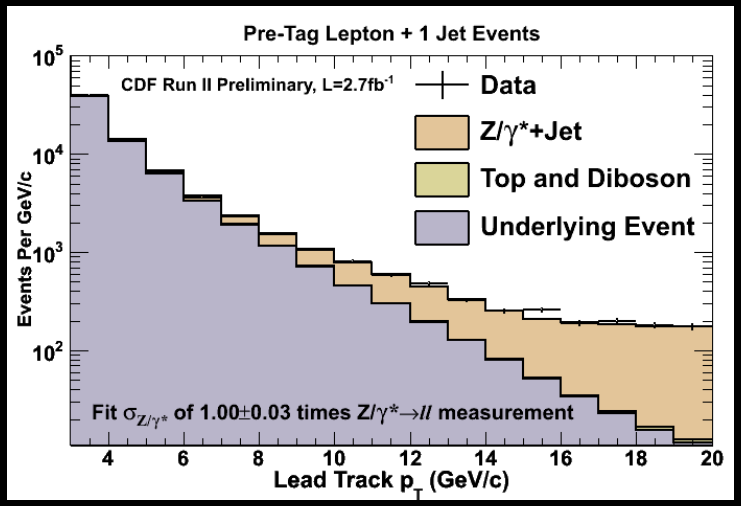
- LEP and D0 limits:
  - Unlikely that top decays to H^+b under MSSM channel
- Consider NMSSM scenario:
  - H^+ would decay into neutral Higgs, which is excluded at high mass
    - A=>$b\bar{b}$ excluded, so search for:

$$t \rightarrow H^{\pm} b \rightarrow W^{\pm} A b \rightarrow W^{\pm} b \tau \bar{\tau}$$

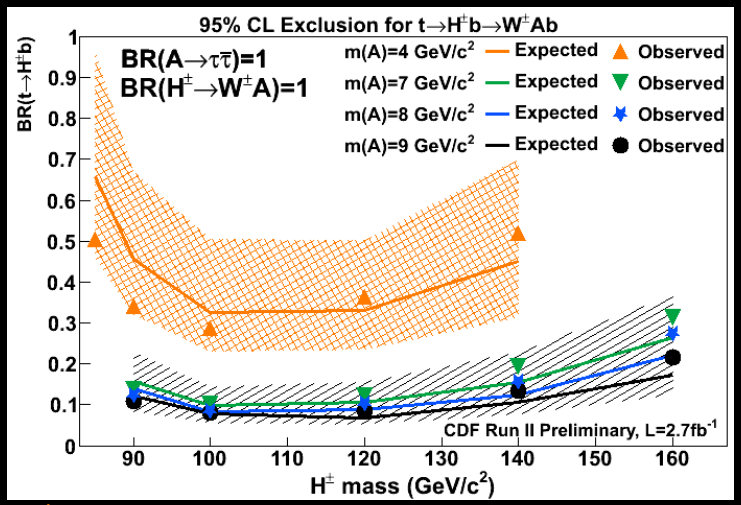
- Final search in $t\bar{t}$ single lepton channel
  - Separate from SM $t\bar{t}$ by searching for an extra low-pT isolated track (from a tau decay)

Backgrounds and Results

- Most challenging background:
  - $t\bar{t}$ with extra track from underlying event
  - Model underlying event from jet-triggered data
    - Validate with Z+jet cross section measurement from fit to track-pT
- No excess signal
  - Set limits on NMSSM parameters (2.7 fb^{-1})



Validation of Underlying Event Model: Fit to Z+Jet Cross Section



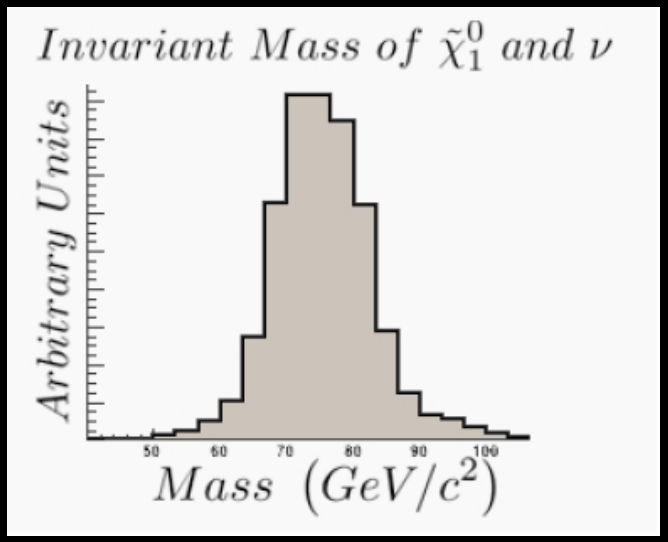
2.7 fb^{-1} Limits on t=>H^+b Branching Ratio Depending on NMSSM parameters

Conclusion

- Tevatron has produced enough top statistics for high-precision measurements
  - Possible to constrain many exotic physics scenarios
- Many direct searches for new physics have been performed:
  - No evidence of significant rate of heavy X=>$t\bar{t}$
  - No evidence of supersymmetric tops being produced
  - No evidence of tops decaying to charged Higgs
- But still plenty of room for new physics
  - Top charge asymmetry larger than expected at both experiments (>2 sigma at CDF). More statistics being collected!
- Many more studies in next talk

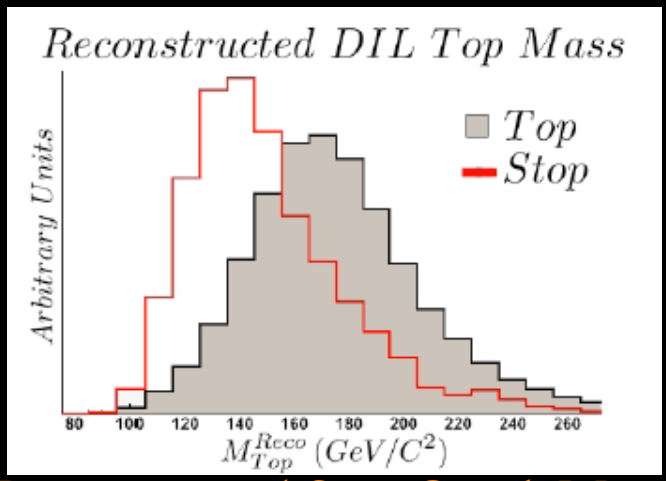
CDF Stop Mass Procedure

- Challenge to reconstructing top quark mass:
  - System is underconstrained
    - Two invisible particles from each chargino decay
  - Approximation: treat each neutralino + neutrino as one massive pseudo-particle



Invariant "Pseudo-Particle" mass of Neutralino-Neutrino

- Pick hypothesis pseudo-particle momenta that best satisfy chi2 constraint
  - Sum over phi-directions of pseudo-particles, weighted by chi-square probability



Reconstructed Stop Quark Mass

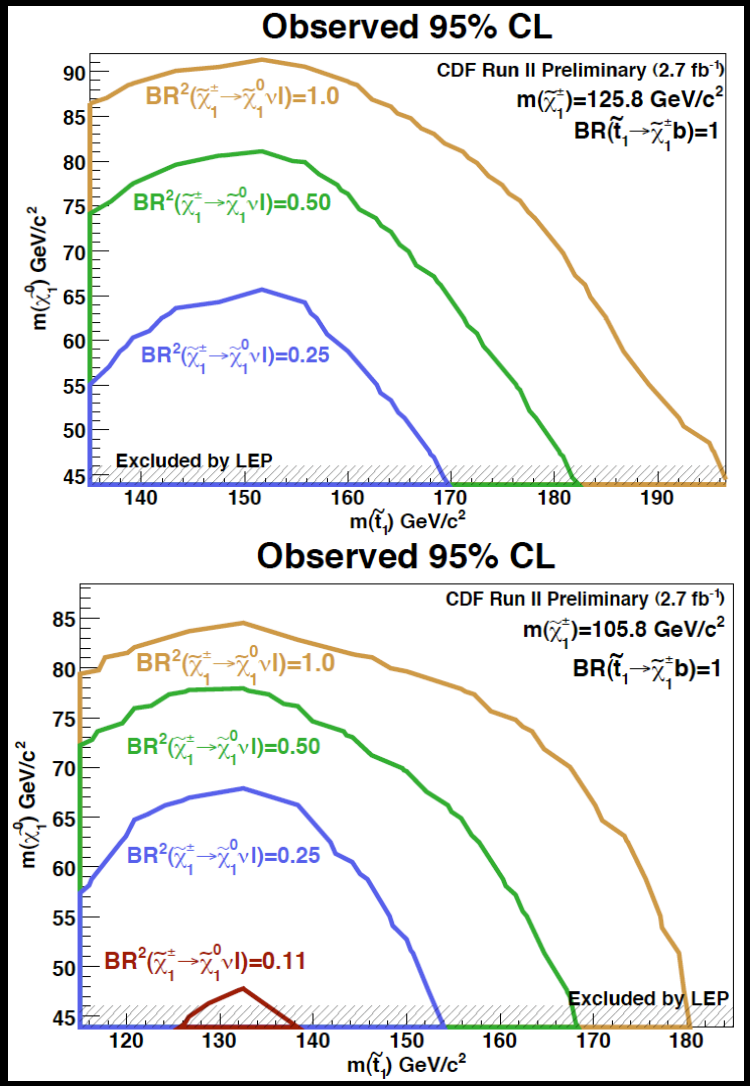
CDF Stop Mass Fit And Limits

- Perform Minuit likelihood fit to reco-top mass
  - Construct test-statistic:

$$Q = \frac{L(data|signal + background)}{L(data|background\ only)}$$

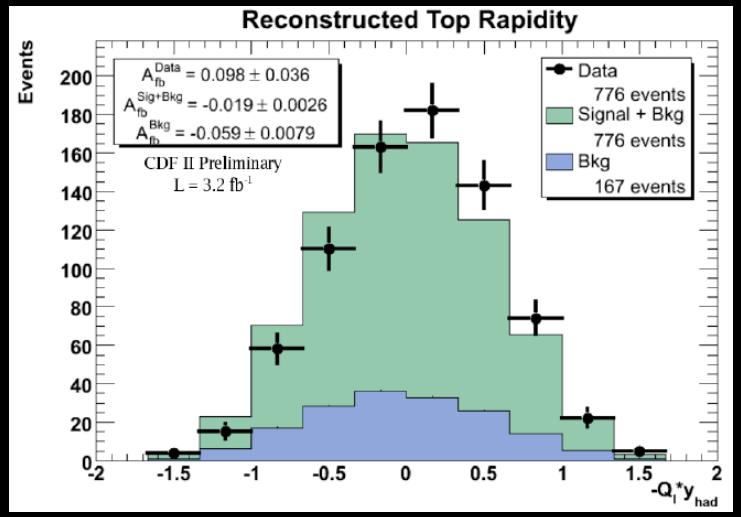
- Use Q in fit to determine 95% confidence limits
  - Systematic uncertainties are nuisance parameters
  - Confidence limits depend on leptonic branching ratio, masses of susy particles

CDF 2.7 fb^{-1} Exclusion Limits For Different Chargino Masses

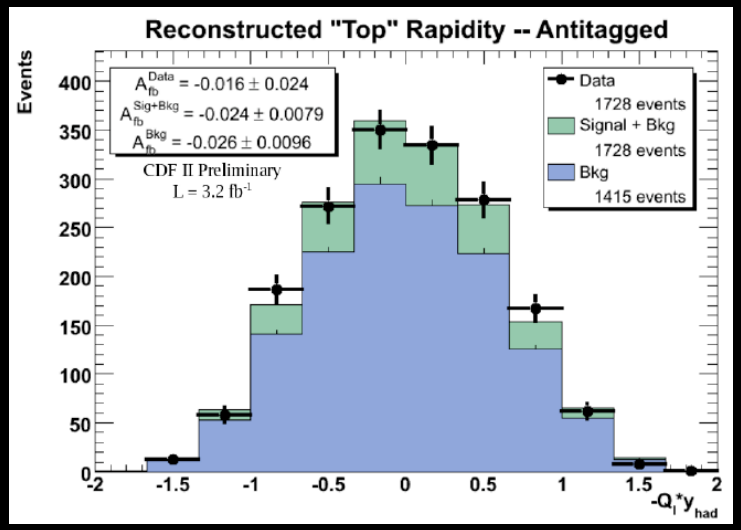


Measurement Methodology

- Work in single lepton channel
  - Reconstruction: Determine parton assignment with chi2 minimization
  - Lepton determines charges of each top
  - Use hadronic top to determine direction
    - If anti-top then flip sign to determine top direction
- Frame of reference is important!
  - Could transform to $t\bar{t}$-frame, but uncertainties are high
  - Instead report A_{fb} in $p\bar{p}$-frame
    - Dilution: A_{fb} expected ~30% smaller



Noticeable Asymmetry in Reconstructed +Charge Top Quark Rapidity



Must subtract backgrounds. Well modeled in sample with no *b*-tags.